Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia Engineering 37 (2012) 137 – 142

Procedia Engineering

www.elsevier.com/locate/procedia

The Second SREE Conference on Engineering Modelling and Simulation (CEMS 2012)

A Numerical Model for Predicting Road Surface Temperature in the Highway

Tao Feng[a],Shide Feng[b]

[a]*Beijing Meteorological Service Center ,Beijing,100089,China*

[b]*Institute of Atmospheric Physics,Chinese Academy of Sciences,Beijing,100029,China*

Abstract

Based on the surface energy balance method, a road surface temperature prediction model is established using solar shortwave radiation, longwave radiation, sensible and latent heat fluxes,and surface heat flux. The numerical model for the prediction of road surface temperature has been tested on data from two road stations in the summer and winter.Observations from the Luilongguan and Yangfang staions in the highway are used to compare with the model simulations.The results show that the road surface temperature predictions are well correlated with the observations under the three weather conditions (sunny, cloudy, overcast).Correlation coefficients are higher than 0.90. It is relatively low in rainy and snowy conditions. The results are generally encouraging and indicate that the road surface temperature prediction model has a good performance.

Keywords: numerical model;energy balance;road surface temperature;summer;winter

1. Introduction

In summer and winter vast areas in many countries experience extremely high temperature,snow,ice,and frost.Such adverse weather conditions lead to dangerous driving conditions

*Corresponding author. Tel.:+86-15201055300; fax:+86-010-68400599.
E-mail address: fengtao@mail.iap.ac.cn.

1877-7058 © 2012 Published by Elsevier Ltd. Open access under CC BY-NC-ND license.
doi:10.1016/j.proeng.2012.04.216

with consequential effects on road transportation. In summer hot weather can impact tires severely which can cause tire blowouts.In winter provision for a road surface temperature forecast is essential information for a highway engineer, allowing cost effective salting decisions regarding winter road maintenance.Therefore, more accurate prediction of road surface temperature is expected by the users.

Road surface temperature has been studied for many years. In 1957, Barber [1] has used infinite surface temperature medium periodic variations of heat conduction equations to determine the maximum road surface temperature. In 1972, Christison and Andenson [2] have studied the pavement temperature conditions under the low temperature condition. In 1997, B.H.Sass [3] has developed a numerical forecasting system which is presented for automatic prediction of slippery road conditions at road station sites in Denmark.In 2000,Hermansson [4] has developed a simulation model to calculate the temperatures of asphalt concrete during the summer.

In China minor scientists have studied road surface temperature who mostly utilize the statistical method. Qin Jian [5] has utilized the regression analysis between the measured road surface temperature data and meteorological data in several regions and developed a model to predict road surface temperature. Zhuang Chuanyi [6] has analyzed the relation between road surface temperature and air temperature,solar radiation intensity and rainfall and established the prediction model of surface temperature on sunny, cloudy,and rainy days.

In this paper, based on the surface energy balance method, the numerical model to calculate road surface temperature in the highway is established. A detailed comparison is made between the prediction and observation of the road surface temperature from two road weather stations in the highway.

2. Road surface temperature prediction model

The basic equation of energy transfer climatology is the energy conservation law.Surface energy balance equation is described as[7]

$$R_N + LE + H + S = 0 \tag{1}$$

where, R_N is net radiation; LE and H is the latent heat flux and sensible heat flux, respectively; S is surface heat flux.The net-radiative flux is composed of the net short-wave radiation flux, as determined by beam and diffuse solar radiation （$Q+q$）and albedo （α） and the net thermal radiation.

$$(1-\alpha)(Q+q) + \sigma T_{sky}{}^4 - \sigma T_0{}^4 = R_N \tag{2}$$

Where, σ is Stefan-Boltzmann constant , T_{sky} is air temperature, T_0 is road surface temperature.

2.1. Calculation of solar shortwave radiation and solar longwave radiation [8]

Solar shortwave radiation is composed of the direct solar radiation and the scattered solar radiation. Direct solar radiation can be expressed as

$$Q = \left(\frac{2\times 10^3}{R^2}\cos z\right)\Psi \tag{3}$$

$$\cos z = \sin(L)\sin(d) + \cos(L)\cos(d)\cos(\omega) \tag{4}$$

$$\Psi = \exp[-0.089\times(Pm/1013.0)^{0.75} - 0.174\times(wm/20)^{0.6} - 0.083\times(Dm)^{0.9}] \tag{5}$$

$$m = \left|1.0/\cos z\right|(P/1013.0) \tag{6}$$

Where, L is the geographic latitude, d is solar declination angle, ω is time angle. w is precipitation （mm）, D is the dust particles（cc）.Diffuse solar radiation can be expressed as

$$q = 0.5\times(2\times10^3/R^2)\cos z(1-\exp(0.083(Dm)^{0.9})) \tag{7}$$

Net longwave radiation is composed of the ground emitting longwave radiation($L\downarrow$)and atmospheric counter radiation($L\uparrow$).

$$L\downarrow = \sigma T_{sky}{}^4 \tag{8}$$

$$L\uparrow = \sigma T_0^4 \tag{9}$$

2.2.Calculation of sensible heat and latent heat[9]

$$H = CK[T_2 - \Gamma Z_2 - T_0] \tag{10}$$

$$LE = LK[q_2 - q_0] \tag{11}$$

$$K = (k^2 U_2 \rho)[\ln Z_2 / Z_0]^2 \tag{12}$$

Where, C is the heat capacity of the air; L is the latent heat of condensation, T_0 and q_0 is road surface temperature and relative humidity, respectively. ρ is the air density, k is Von Karman constant, U_2 is the upper wind speed, Z_2 is wind speed, Z_0 is surface roughness layer.

2.3 Surface heat flux

$$S = K_s / (Z_s / 2)[T_h - T_0] \tag{13}$$

Where, S is the surface heat flux, K_s is the thermal conductivity, Z_s is the level.

2.4 Road surface temperature

Thus,surface energy exchange can be expressed as

$$\begin{aligned}&(1-\alpha)(Q+q)+\sigma T_{sky}{}^4-\varepsilon\sigma T_0^4+\frac{\rho k U_2}{[\ln Z_2/Z_0]^2}\\&\{C[T_2-\Gamma Z_2-T_0]+L[q_2-\frac{X_\omega}{L}f(T_0)]\}+\frac{Ks}{(Z_s/2)}(T_h-T_0)=0\end{aligned} \tag{14}$$

This value calculated by iterative substitution on digital computers is termed the equilibrium surface temperature. The iteration loop is exited when the error of the absolute sum of the components of surface energy transfer is less than 1 $mly./\min$.

3. Validation of road surface temperature prediction model

In this paper the observation data is obtained from the Huilongguan and Yangfang road weather stations in the highway.

3.1.Comparision between predicted and measured road surface temperature in the summer

Road surface temperature prediction is compared with the observation under four different weather conditions (sunny, cloudy, overcast, rainy).The results are shown in Fig. 1 and Fig.2.

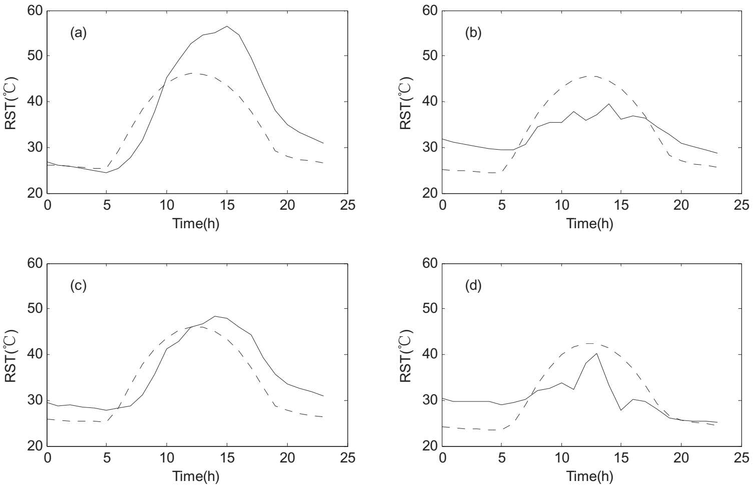

Fig.1. Comparison with prediction and observation of road surface temperature(RST) in July 2011 at the Huilongguan station in Badaling expressway under different weather conditions ((a) sunny; (b) overcast; (c) cloudy; (d) rainy)

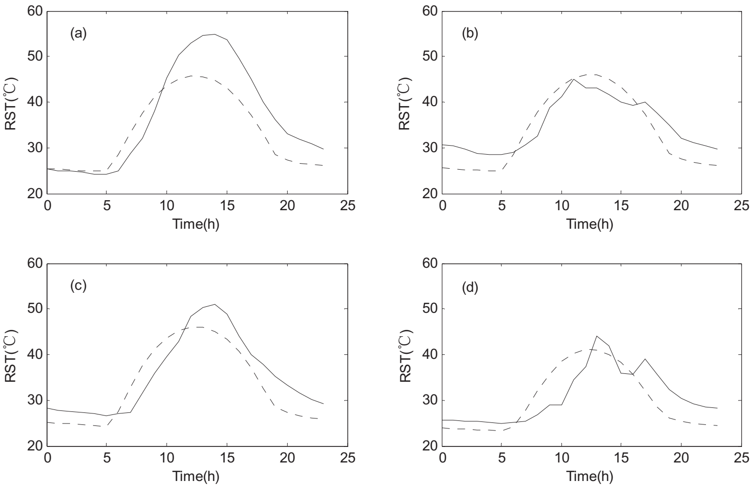

Fig.2. Comparison with prediction and observation of road surface temperature(RST) in July 2011 at the Yangfang station in Jinjintang expressway under different weather conditions ((a) sunny; (b) overcast; (c) cloudy; (d) rainy)

It can be seen from Fig. 1 and Fig.2 that correlation coefficients between prediction and measured road surface temperature at two stations are about 0.90 under different weather conditions such as sunny, overcast and cloudy, but it is relatively low under rainy day.

3.2.Comparision between predicted and measured road surface temperature in the winter

Road surface temperature prediction is also compared with the observation under four different weather conditions (sunny, cloudy, overcast, snowy).The results are showed in Fig. 3 and Fig.4.

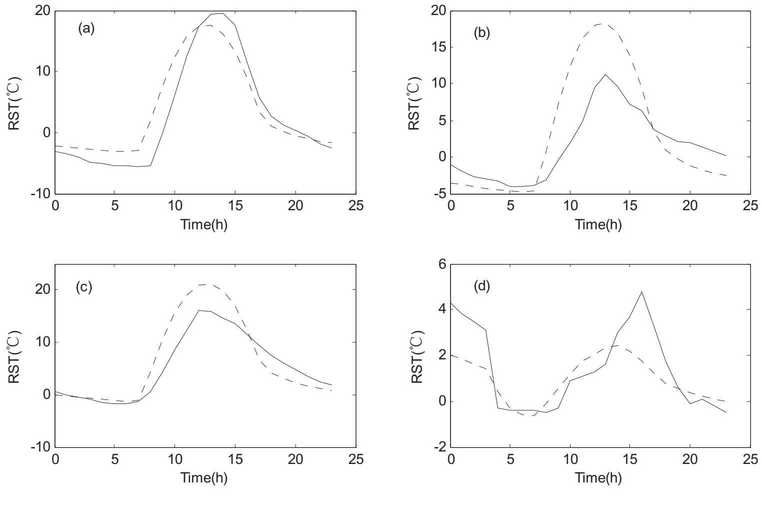

Fig.3. Comparison with prediction and observation of road surface temperature(RST) in February 2011 at the Huilongguan station in Badaling expressway under different weather conditions ((a) sunny; (b) overcast; (c) cloudy; (d) snowy)

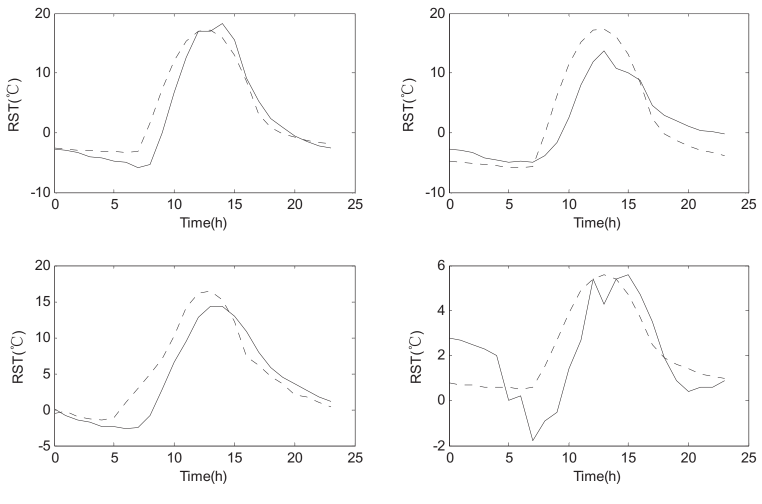

Fig.4. Comparison with prediction and observation of road surface temperature(RST) in February 2011 at the Yangfang station in Jinjintang expressway under different weather conditions ((a) sunny; (b) overcast; (c) cloudy; (d) snowy).

The experimental results show that correlation coefficients between prediction and observation of road surface temperature at two stations are about 0.90 under three weather conditions (sunny, overcast, cloudy), The maximum value is 0.95, but it is relatively low under snowy condition.

4. Conclusion

Based on energy conservation method, a road surface temperature prediction model is established using solar shortwave radiation, longwave radiation, sensible and latent heat fluxes,and surface heat flux.From the results of the validation study, the following conclusions can be drawn.

(1) The road surface temperature prediction model has been tested on data for two road weather stations in the summer and winter.Correlation coefficients between prediction and observation of road surface temperature are about 0.90 under three weather conditions (sunny, overcast, cloudy). Correlation coefficients in rainy and snowy conditions are relatively low. However,the results are generally encouraging.The results indicate that the prediction model has a good performance.

(2) For operational use, if the model can be combined with the high resolution numerical weather forecast, it will provide accurate prediction of road surface temperature for up to 24h ahead.

(3) The model is simulated under ideal conditions. The influence of geographical parameters such as altitude, topography and sky-view factors on the climatology of the road need to be studied.

Acknowledgements

This study was supported by the Joint Funds of the National Natural Science Foundation of China (Grant No. 41175057), the National Natural Science Foundation of China (Grant No. 40927002),the National Natural Science Foundation of China (Grant No. 40875036),and the National Natural Science Foundation of China (Grant No. 40675029).

References

[1] Barber ES.Calculation of maximum pavement temperatures from weather reports.Highway Research Board,Bulletin 168,National Research Council,Washington DC,1957.

[2] Christison JM,Anderson KO.The response of asphalt pavements to low temperature climatic environments.Proceeding of the 3rd International Conference on the Structural Design of Asphalt Pavements,1972.

[3] Bent HS.A numerical forecasting system for the prediction of slippery road. *J.Appt.Meteor*., 1997,36(6):801-817.

[4] Hermansson A.A simulation model for calculating pavement temperature, including the maximum temperature.Transportation research board 79th annual meeting. Washington D C,2000.

[5] Qin Jian,Sun Tijun.Study on asphalt pavement temperature field distribution pattern.*Journal of Highway and Transportation Research and Development*,2006,23(8):18-21.

[6] Zhuang Chuanyi,Wang Lin,et al.Prediction model of surface temperature of asphalt pavement.*Journal of Highway and Transportation Research and Development*, 2010,27(3):39-48.

[7] Chapman L, Thornes JE,et al. Modelling of road surface temperature from a geographical parameter database. Part 2: Numerical. *Meteoro Mag*,2001,8(114): 421–436.

[8] Jacobs W,Raatz WE.Forecasting road surface temperatures for different site characteristics.*Meteorol Appl*,1996,3(3):243-256.

[9] Myrup LO. A numerical model of the urban heat island.*Journal of Applied Meteorology*, 1969,8: 908-919.